Mining-induced subsidence prediction by Displacement Discontinuity Method

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Abstract
It is essential to predict the mining-induced subsidence for sustainable mine management. The maximum observed subsidence having a noticeable areal extent due to Northern Upper Panels (NUP) and Southern Lower Panels (SLP) at the Barapukuria longwall coal mine is 5.8 m and 4.2 m, respectively, after the extraction of a 10 m thick coal seam. The mining-induced subsidence was simulated by the Displacement Discontinuity Method (DDM). The numerical model considered the effects of the ground surface, mining panels, faults, and the dyke. The predicted and the observed subsidence due to the mining of NUP and SLP were compared varying Young's modulus, and the 0.10 GPa Young's modulus was found to be the best match. The effects of the faults and the dyke in the calculation were found to be negligible. Future subsidence was predicted by considering 30 m extraction of the thick coal seam as 15.7 – 17.5 m in NUP and 8.7 – 10.5 m in SLP. For proper/sustainable mine management, the mining authority might need to count on this subsidence issue.

Keywords: DDM, Young’s modulus, Longwall coal mining, Faults, Dyke

1. Introduction

In the longwall coal mining method, subsidence is allowed, and because of that, the stress-induced accidents are lower in this mining system, having a higher production rate. As subsidence is a must in a longwall coal mine without stowing, it is essential to predict the mining-induced subsidence for sustainable mine management. In this research, we have tried to predict the mining-induced subsidence of the Barapukuria longwall coal mine by the Displacement Discontinuity Method (DDM) was originally developed by Crouch and Fairhurst [4].

2. General Characteristics of the Coal Basin

Barapukuria coal basin is located in the northwestern part of Bangladesh (Figure 1). The coal basin is a graben, an asymmetrical faulted syncline (Figure 1), with an approximately N-S axis. The rock sequence of the coal basin consists of the following five units. (1) Madhupur Clay Formation (2) Upper Dupi Tila Formation (3) Lower Dupi Tila Formation (4) Gondwana Formation and (5) Basement Complex.

The Madhupur Clay Formation which is Holocene to recent in age is about 1–15 m thick [1, 2]. The Dupi Tila formation is mainly a Late Miocene –Middle Pliocene aged layer. The Upper Dupi Tila Formation, which is mainly an unconsolidated to partly consolidated sand layer; with medium to coarse grained, occasionally gravelly with bands of silt with an average thickness of about 94 to 126 m in the basin [1, 2], having the thickness of almost 100 m in the mine area (Figure 1). The Lower Dupi Tila Formation consists of sandstone, silt and white clay, and the thickness varied from 0 to 80 m in the basin [1, 2] which is 0 to 60 m in the mine area (Figure 2). The Gondwana the basin [1, 2] which is 0 to 60 m in the mine area (Figure 2). The Gondwana Formation is a Permian aged coal bearing rock layer that unconformably lays on the Basement Complex.

This rock sequence is up to 390 m thick [1, 2] in the basin which is about 150 -300 m in the mine area (Figure 1) consisting of predominantly arkosic sandstone with subordinate siltstones, shales and, breccia-conglomerates with occasional interbedded siltstone, sandstones [2]. The average thickness of the thickest coal-seam of the basin is about 36 m. The coal seam has a gentle slope of 13° to 19° and it is dipping towards the east. The Basement Complex is mainly a layer of diorite, meta-diorite, ophlitic gneiss, and granite rock [2].

The uniaxial compressive strength of the coal bearing rock (Gondwana Formation)

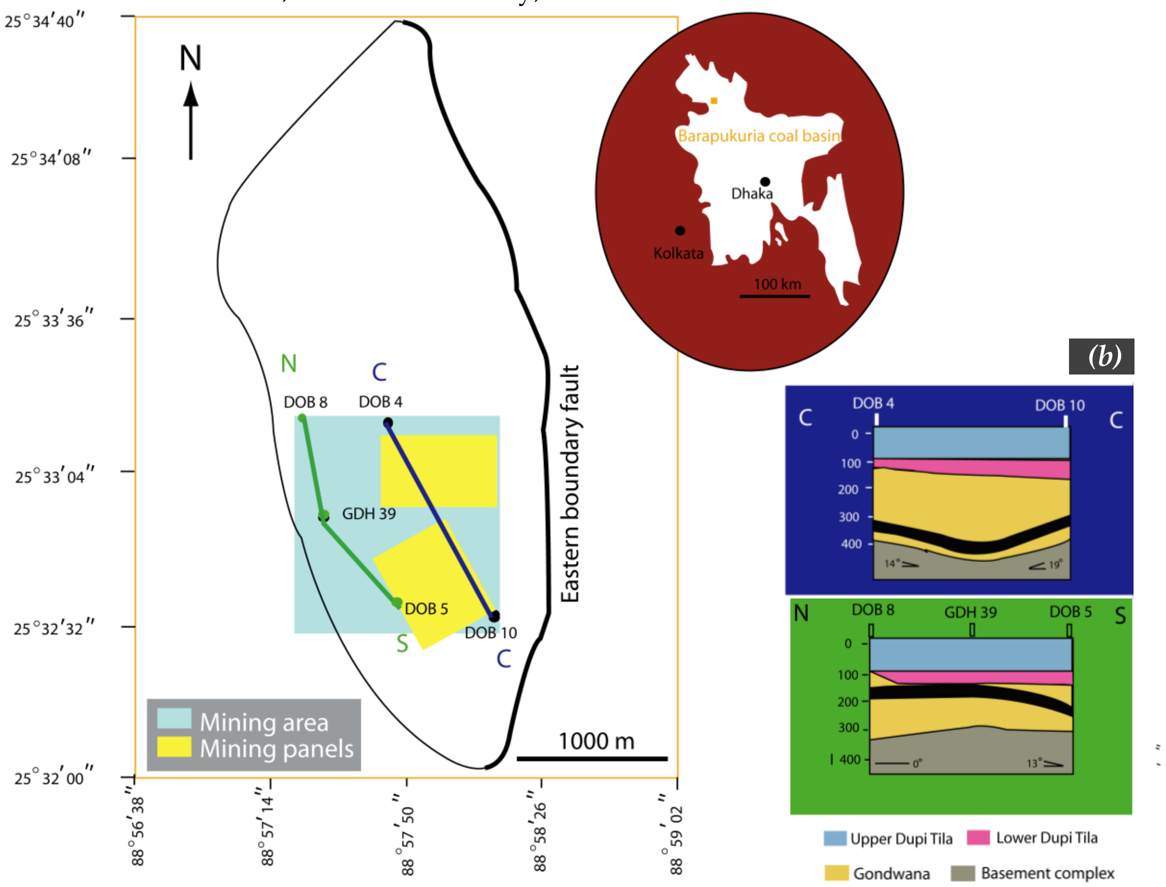

Figure. 1: Barapukuria coal basin (a) and the associated rock layers (b) with the thickest coal seam [1].

varies from 35.61 ± 17.08 MPa (DOB 5) with a bulk density of 2.30 ± 0.20 g/cm³ to 12.34 ± 6.61 MPa (DOB 8) with a bulk density of 2.02 ± 0.36 g/cm³ (Figure 2). The rock is stronger in the southern part (DOB 5, DOB 10) of the mine area than the northern part (DOB 4, DOB8).

The western part is more faulted than the southern part of the basin (Figure 3). Faults bound the basin east by Eastern Boundary Fault (EBF) and west by numerous faults (Figure 3). The faults within the basin can be divided into (1) intra-basinal faults, and (2) boundary faults. The EBF is downthrown at 70°–75° in the west and having vertical displacement about 200 m is around 5 km in length with NNW-SSE and N-S strike. The faults of the west have the strike mainly of NNW – SSE and in some portion of about NNE-SSW. There are several numbers of intra-basinal faults with the throw about 10 m within the coal bearing rock layer in the mine area. A dyke which is an igneous intrusion has been detected in the northern mining panels with a strike of around NEE- SWW.

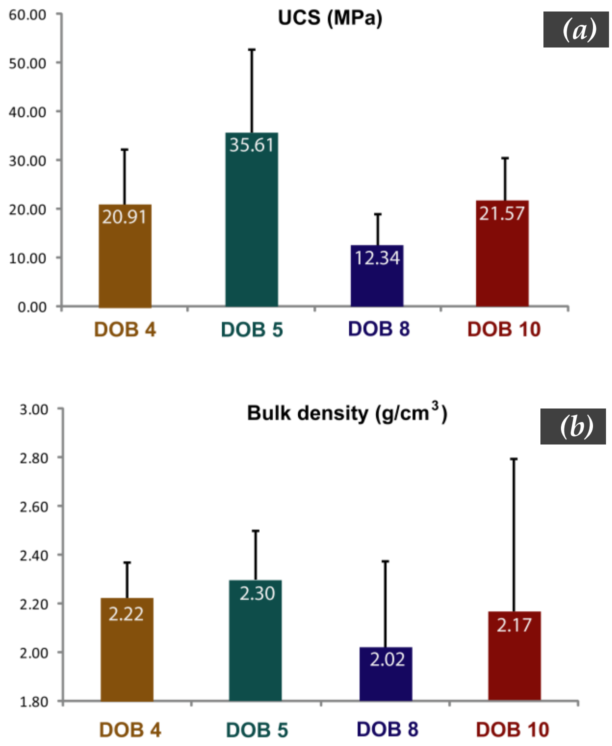

Figure. 2: The uniaxial compressive strength (a) and bulk density (b) of the rock from the coal bearing formation of the mine area.

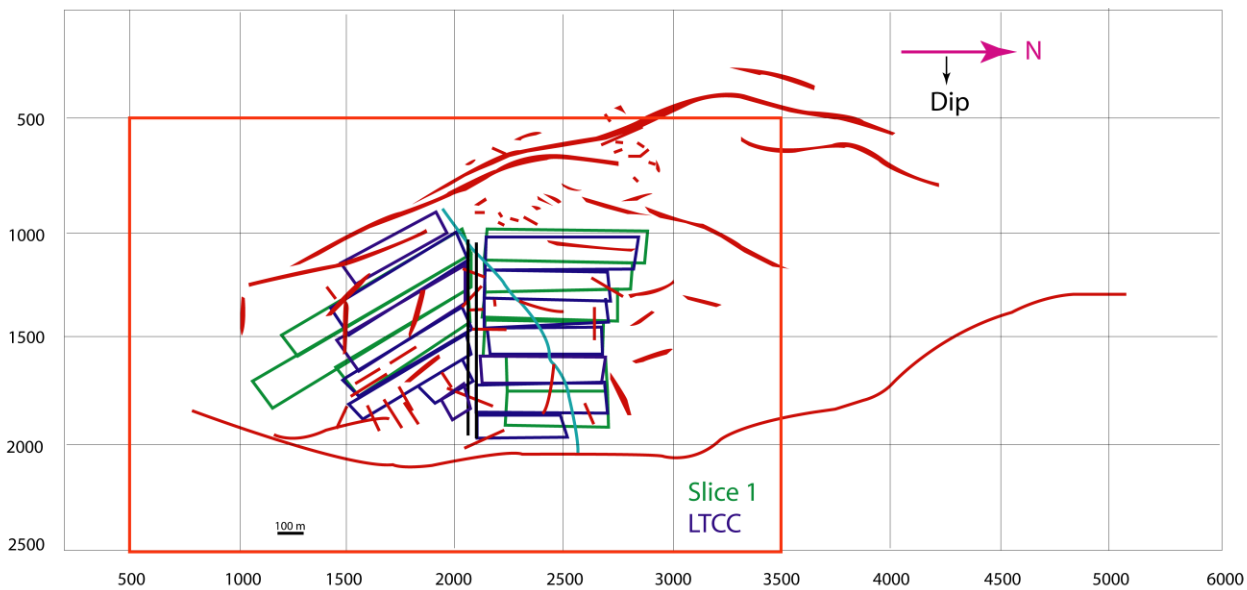

Figure. 3: The faults (red) and a dyke (cyan) of the Barapukuria coal basin and the mining panels [3].

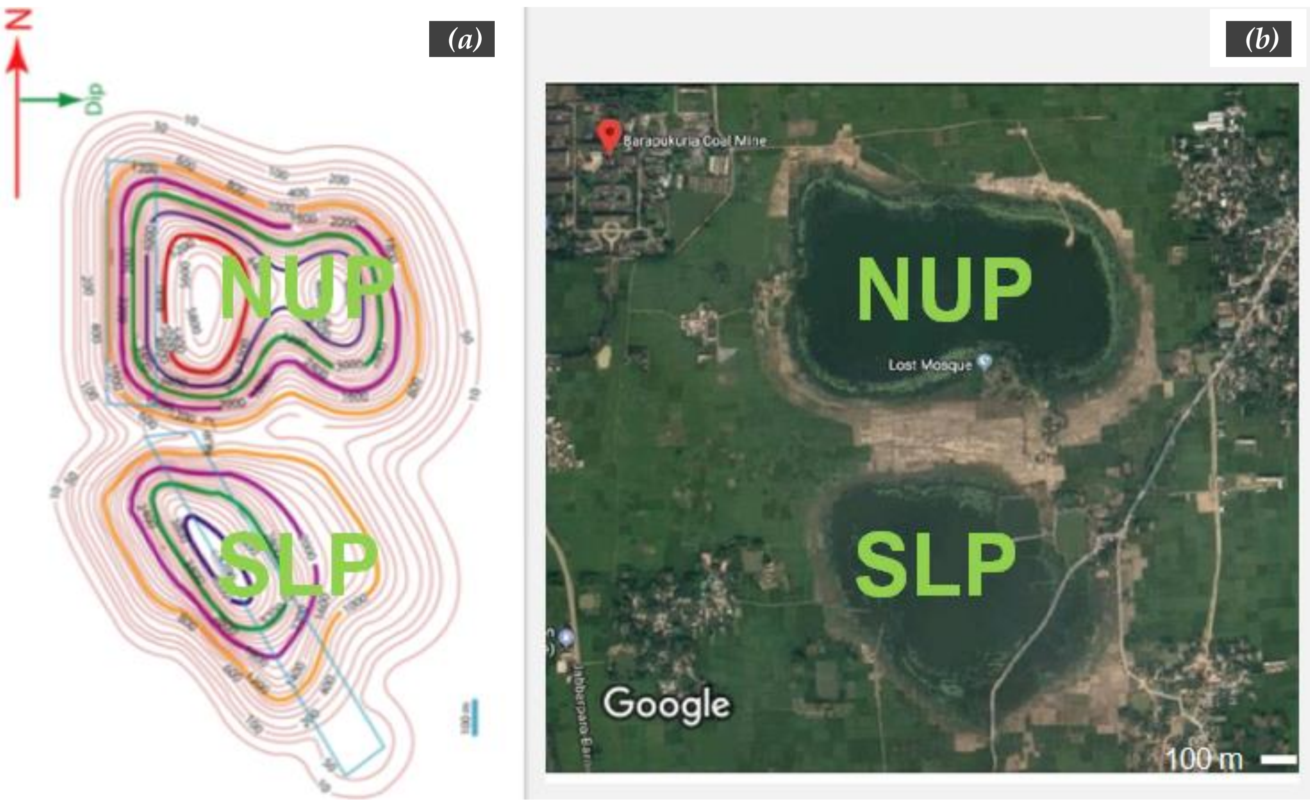

Figure. 4: The subsidence in the mine area (a) Contour of the subsidence (b) The subsided area.

3. The observed subsidence

The subsidence in the mining area can be divided into two regions i.e., the northern and southern parts considering the subsidence epicenters (Figure 4b). The subsidence in the north is just above the Northern Upper Panels (NUP), and the south is above the Southern Lower Panels (SLP). The observed subsidence is shown as a contour map in Figure 4a. The subsidence in the north can be further subdivided into North-Western and North-Eastern zones. The maximum subsidence in the North-Western and the North-Eastern zones is 5.8 m and 4.6 m, respectively (Figure 4a). The maximum subsidence of 4.2 m was observed in the southern part.

The observed subsidence of the contour map was converted to grid values having specific range in the modeled grid area (Figure 5) is to compare the observed and the predicted subsidence.

4. Numerical simulation of the subsidence by DDM

The subsidence was numerically calculated by DDM, a kind of the boundary element method (BEM), and was originally developed by Crouch and Fairhurst [4] especially aiming for the application to tabular excavations. They presented algorithms to effectively obtain elastic solutions for mine-wide stress change due to the mining of parallel ore seams. In the algorithm, ore seams are divided into square displacement discontinuity (DD) elements, and boundary conditions are assigned according to the mining indices, which were unmined, mined, or closed. Simultaneous equations, each representing stress change in an infinite elastic body by a DD element, are solved to obtain the elastic solution. The above method was modified by the current authors so that

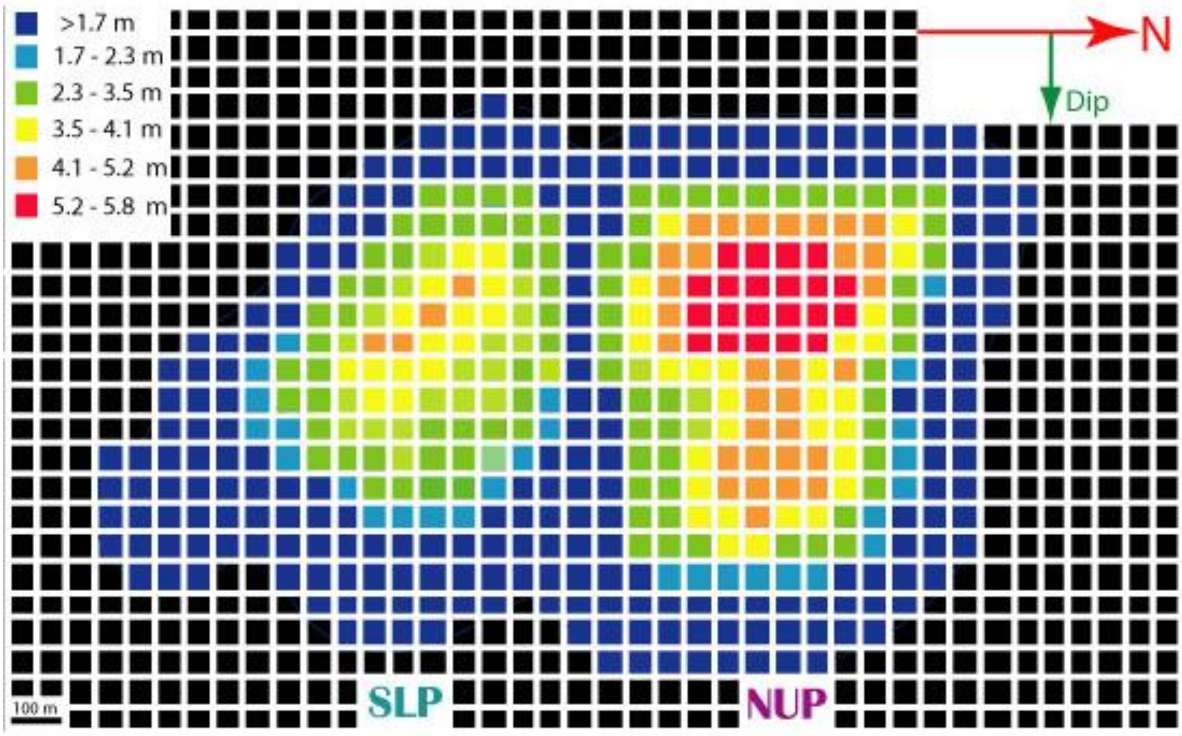

Figure. 5: The observed subsidence as grid values in the mine area.

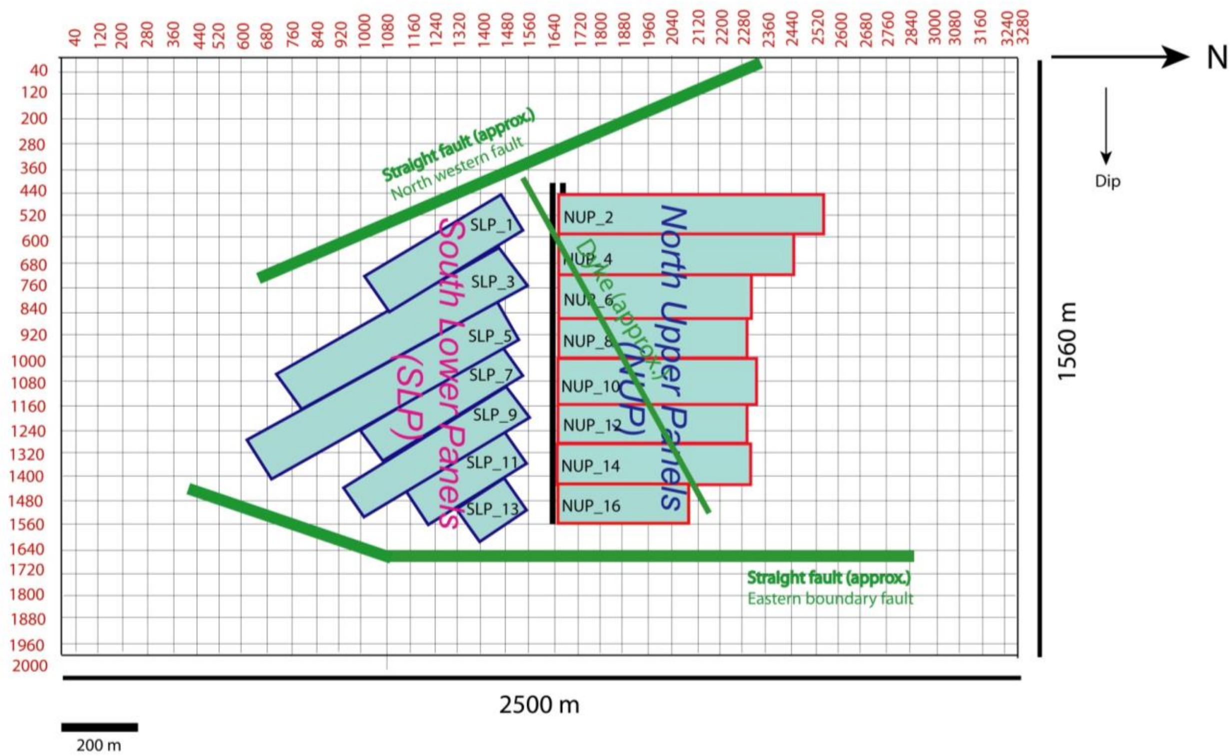

Figure. 6: The mine model with mine panels and main discontinuities.

the ground surface, mining panels, faults, and dykes at any orientations could be divided by rectangular DD elements and used here. The ground surface of 2500 × 1560 m² was divided by 40 × 25 DD elements, and the free surface condition was assigned. Each mining panel, fault, or dike was approximated by a rectangular plane (Figure 6) and was divided 4 - 22 DD elements. The element division is not fine enough due to the memory limitation. The limitation is not a hardware but a software problem. BEMs, including DDM, generally require much more memory space than FEMs (finite element methods). Moreover, the used compiler (Microsoft FORTRAN Power Station, ver.4.0), which is not the latest version, generates only 32-bit executables. This problem should be solved in the future.

The mining height was assigned as 10 m as on average, the first 3 m slice of coal was extracted by conventional longwall mining, and the next 7 m slice was extracted by longwall top coal caving (LTCC) method. Friction angle of 30° was assigned to the faults and the dyke.

The calculation should be carried out for the case in which the ground surface, mining panels, faults, and the dyke existed (Case1) and the case without mining panels (Case2), and subsidence for Case2 was subtracted from that for Case1 to obtain subsidence by mining panels. However, calculation with the ground surface and mining panels (Case3) was carried out first for simplicity. The calculated results show a peak at NUP and another peak at SLP for lower Young's modulus and only one peak for at NUP for higher Young's modulus (Figure 7).

5. Discussions

5.1 The selection of the best value for Young's modulus

The peak values are saturated by the closure of the mining panels for lower Young's modulus and decrease with Young's modulus (Figure 8). As a result of the comparison between the calculated results with the observation, Young's modulus of 0.1 GPa was selected as the best value. The predicted subsidence distribution (Figure 7, 0.1 GPa) well simulated the observed one (Figure 5) with a slightly different areal extent.

The Young's modulus of rock, rock-like material, and rock mass varies with environmental conditions [5]. It is also known that Young's modulus of the rock mass is much smaller than the Young's modulus of intact rock specimens. In other words, it is not easy to deterministically fix Young's modulus value. The above selection of Young's modulus value can be considered as a back analysis.

5.2 Effects of the faults and the dyke

The subsidence due to mining panels, faults, and the dyke (Figure 7, 0.1 GPa) is almost the same as the subsidence without faults and the dyke (Figure 9a). The contribution by the faults and the dyke is almost negligible (Figure 9b).

5.3 Future subsidence

The future subsidence was predicted by considering a 30 m thick coal extraction of the thickest (36 m) coal seam. The maximum subsidence of 15.7 – 17.5 m in the NUP and 8.7 – 10.5 m in the SLP is predicted in the mining area (Figure 10). For proper/sustainable mine management, the mining authority should count on this subsidence issue.

6. Concluding remarks

The maximum observed subsidence having a noticeable areal extent due to Northern Upper Panels (NUP) and Southern Lower Panels (SLP) at the Barapukuria longwall coal mine is 5.8 m and 4.2 m, respectively, after the extraction of a 10 m thick coal seam (Figure 5). The mining-induced subsidence was simulated by the Displacement Discontinuity Method (DDM). The numerical model considered the effects of the ground surface, mining panels, faults, and the dyke. The predicted and the observed subsidence due to the mining of NUP and SLP were compared varying Young's modulus, and the 0.10 GPa Young's modulus was found to be the

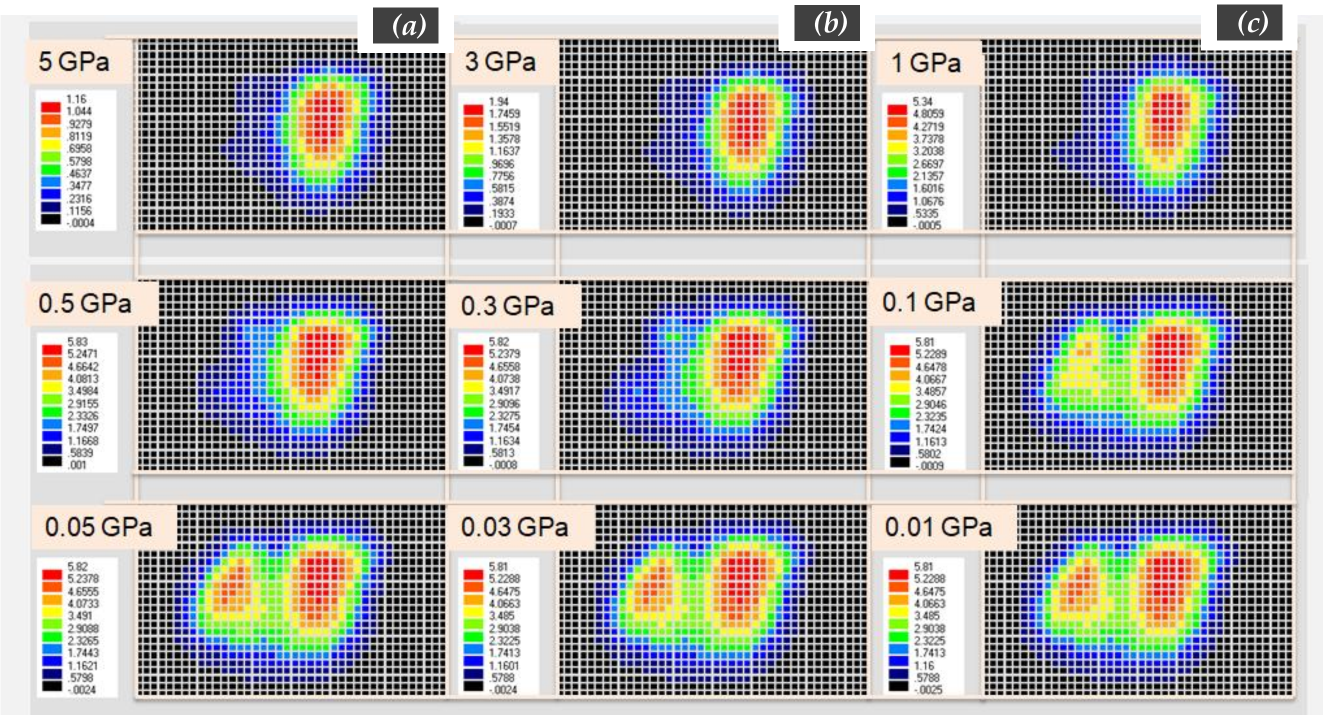

Figure. 7: Calculated subsidence considering Young's modulus of (a) 5 GPa (b) 3 GPa (c) 1 GPa with a logarithmic decrement.

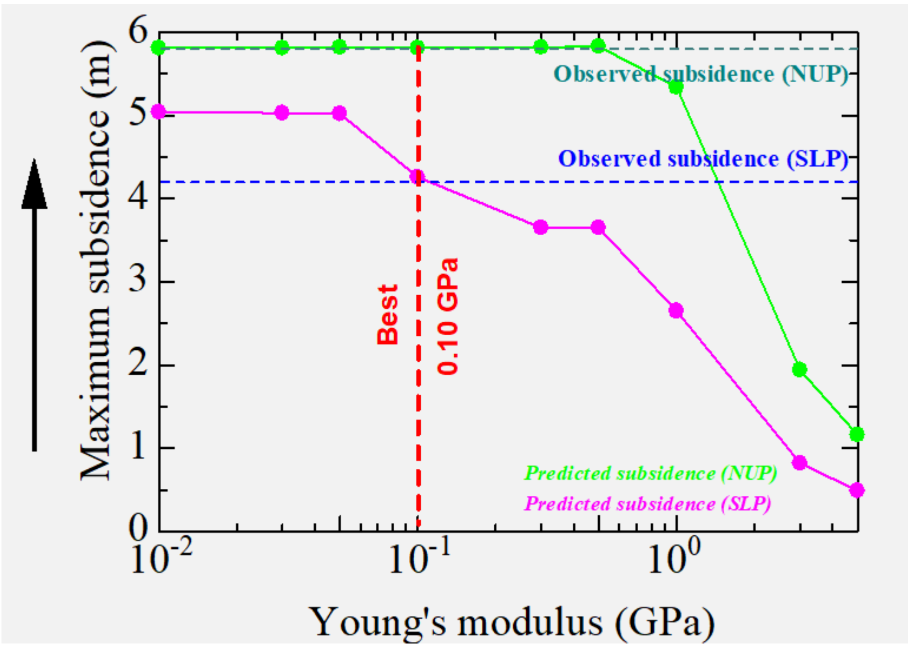

Figure. 8: Young's modulus effect in the predicted subsidence.

best match (Figure 7, 0.1 GPa). The effects of the faults and the dyke in the calculation were found to be negligible (Figure 9b). Future subsidence was predicted by considering 30 m extraction of the thick coal seam as 15.7 – 17.5 m in NUP and 8.7 – 10.5 m in SLP (Figure 10). For proper/sustainable mine management, the mining authority might need to count on this subsidence issue.

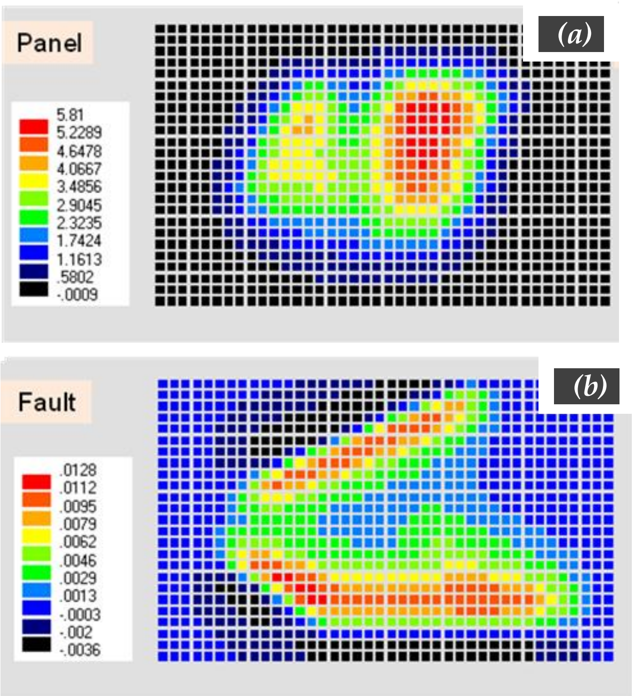

Figure. 9: The subsidence due to panel extraction with faults and the dyke effect (a) and, faults and the dyke (b).

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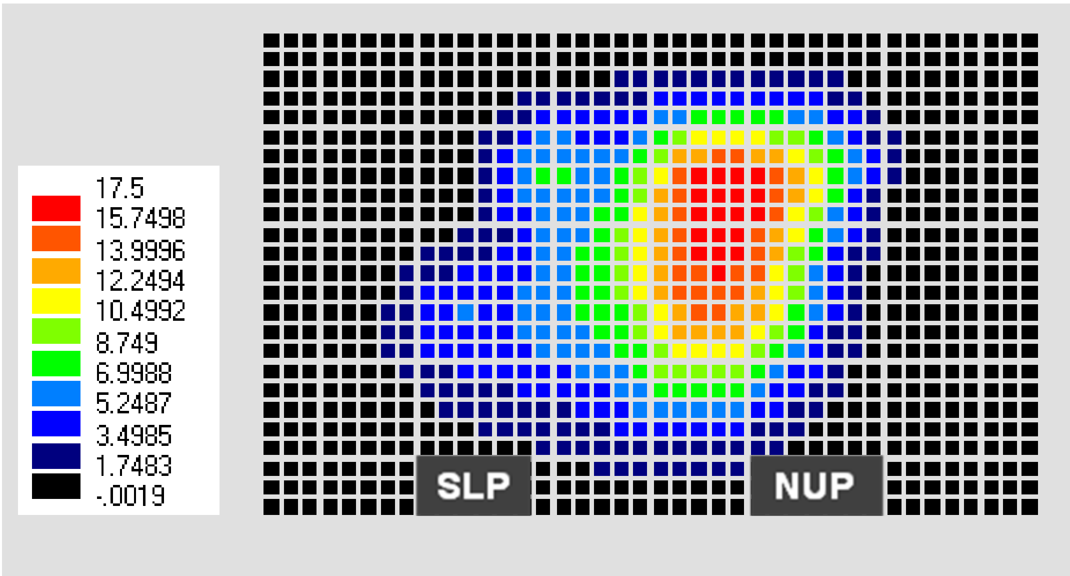

Figure. 10: Future subsidence due to total extraction of 30 m coal seam.